# Exhibit 10

# THE BASICS OF FAN PERFORMANCE TABLES, FAN CURVES, SYSTEM RESISTANCE CURVES AND FAN LAWS

Engineers and designers who select and specify fans should have a good basic knowledge of the content of this article. An understanding of these subjects is vital for verifying the original fan selection, trouble shooting after the installation, and understanding future flexibility.

## Fan performance tables

Manufacturers typically publish catalogs containing performance or rating tables for each specific fan size. These tables are printed in a compact format, showing only the minimum information necessary to select a fan to match a desired performance. Performance tables are very easy to use for making an initial selection, and in most cases, only include stable operating points.

Rating tables are published in one of two basic formats arranged with pressure columns and rows of either RPM or CFM. At the bottom of the table, qualifying statements describe how the fan was tested and what losses are included in the performance rating. In many cases, these tables also show sound ratings in either sones or LwA.

## Using the Performance Tables

The following is a portion of a typical performance table as published for low to medium pressure fans. This table is common to most centrifugal and axial fans used for roof mounting, wall mounting and inline applications.

To use the table, find the required static pressure on the upper horizontal axis (example .375 SP), then read down the static pressure column and find the required CFM (example 13791 CFM). Directly below the CFM is the required BHP for that performance (example 1.99). Also shown in this example is the sound rating for the selected performance (11.7 sones). Reading to the left of the selected CFM, you will find the fan RPM, the motor size and the model identifier.

| MODEL | HP | RPM | STATIC PRESSURE IN INCHES OF W.G. | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | | | 0.125 | | | 0.25 | | | 0.375 | | | 0.50 | | | 0.75 | | | 1.00 | | |
| | | | CFM | Sones | BHP | CFM | Sones | BHP | CFM | Sones | BHP | CFM | Sones | BHP | CFM | Sones | BHP | CFM | Sones | BHP | CFM | Sones | BH |
| 420-5 | 1/2 | 220 | 9353 | 6.5 | 0.31 | 7846 | 6.0 | 0.37 | 5075 | 5.5 | 0.35 | | | | | | | | | | | | |
| | | 245 | 10416 | 7.2 | 0.43 | 9104 | 6.7 | 0.50 | 7304 | 6.1 | 0.53 | | | | | | | | | | | | |
| 420-7 | 3/4 | 280 | 11904 | 8.3 | 0.64 | 10785 | 7.7 | 0.73 | 9418 | 7.1 | 0.78 | 7419 | 6.6 | 0.77 | | | | | | | | | |
| 420-10 | 1 | 305 | 12966 | 9.4 | 0.82 | 11959 | 8.8 | 0.94 | 10781 | 8.0 | 1.00 | 9272 | 7.3 | 1.02 | | | | | | | | | |
| 420-15 | 1 - 1/2 | 350 | 14879 | 11.9 | 1.24 | 14037 | 11.2 | 1.38 | 13050 | 10.1 | 1.46 | 11925 | 9.4 | 1.52 | 10562 | 8.6 | 1.54 | | | | | | |
| 420-20 | 2 | 385 | 16367 | 14.4 | 1.65 | 15629 | 13.5 | 1.81 | 14731 | 12.4 | 1.91 | 13791 | 11.7 | 1.99 | 12701 | 10.7 | 2.05 | 9246 | 8.5 | 1.92 | | | |
| | | 415 | 17643 | | | 16982 | | | 16148 | | | 15303 | | | 14363 | | | 12028 | | | | | |

Unstable performance points are not printed

Model Size

RPM required

Motor horsepower size required

BHP at selected performance

CFM selected

Sones at selected performance

The following performance table is typcial for higher pressure fans, such as housed centrifugal fans. There are individual tables for each fan size and wheel type. In most cases, these tables will have shaded areas representing Class I, II and III RPM limits. To use this table, find the required CFM along the left vertical axis (example 14,000 CFM), then move horizontally to the right to the required static pressure column (example 6.00 SP). At this intersection, you can read both the fan RPM and the BHP (example 1277 RPM and 16.8 BHP). Notice these points are located on the lightly shaded portion of the table, indicating that a Class II fan is required.

| CFM | OV | Static Pressure In Inches 2.50 | | 3.00 | | 3.50 | | 4.00 | | 4.50 | | 5.00 | | 5.50 | | 6.00 | | 6.50 | | 7.00 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | RPM | BHP | RPM | BHP | RPM | BHP | RPM | BHP | RPM | BHP | RPM | BHP | RPM | BHP | RPM | BHP | RPM | BHP | RPM | BHP |
| 10000 | 1597 | 848 | 5.01 | 905 | 5.99 | 960 | 7.04 | 1017 | 8.21 | 1071 | 9.41 | | | | | | | | | | |
| 11000 | 1757 | 878 | 5.62 | 931 | 6.62 | 983 | 7.69 | 1032 | 8.80 | 1084 | 10.1 | 1135 | 11.3 | 1184 | 12.7 | | | | | | |
| 12000 | 1916 | 908 | 6.29 | 960 | 7.35 | 1009 | 8.44 | 1056 | 9.59 | 1103 | 10.8 | 1148 | 12.1 | 1197 | 13.5 | 1243 | 14.9 | 1287 | 16.3 | 1330 | 17.8 |
| 13000 | 2076 | 938 | 7.02 | 990 | 8.15 | 1038 | 9.30 | 1083 | 10.5 | 1127 | 11.7 | 1171 | 13.0 | 1213 | 14.3 | 1256 | 15.7 | 1300 | 17.2 | 1343 | 18.8 |
| 14000 | 2236 | 969 | 7.81 | 1020 | 9.01 | 1068 | 10.2 | 1113 | 11.5 | 1155 | 12.7 | 1196 | 14.0 | 1237 | 15.4 | 1277 | 16.8 | 1315 | 18.2 | 1356 | 19.8 |
| 15000 | 2396 | 1000 | 8.67 | 1051 | 9.94 | 1098 | 11.2 | 1143 | 12.5 | 1185 | 13.9 | 1225 | 15.2 | 1263 | 16.6 | 1301 | 18.0 | 1339 | 19.5 | 1376 | 21.0 |
| 16000 | 2555 | 1035 | 9.59 | 1062 | 10.9 | 1129 | 12.3 | 1173 | 13.7 | 1215 | 15.1 | 1254 | 16.5 | 1293 | 17.9 | 1329 | 19.4 | 1364 | 20.8 | 1401 | 22.4 |
| 17000 | 2715 | 1071 | 10.6 | 1116 | 12.0 | 1160 | 13.4 | 1204 | 14.9 | 1245 | 16.4 | 1285 | 17.8 | 1322 | 19.3 | 1359 | 20.8 | 1394 | 22.4 | 1427 | 23.9 |
| 18000 | 2875 | 1108 | 11.7 | 1151 | 13.2 | 1192 | 14.7 | 1235 | 16.2 | 1276 | 17.7 | 1315 | 19.3 | 1352 | 20.8 | 1388 | 22.4 | 1423 | 24.0 | 1457 | 25.6 |
| 19000 | 3035 | 1145 | 12.8 | 1187 | 14.4 | 1228 | 16.0 | 1266 | 17.6 | 1307 | 19.2 | 1346 | 20.8 | 1383 | 22.4 | 1419 | 24.1 | 1453 | 25.7 | 1486 | 27.4 |
| 20000 | 3194 | 1184 | 14.0 | 1224 | 15.7 | 1264 | 17.4 | 1301 | 19.0 | 1338 | 20.7 | 1377 | 22.4 | 1414 | 24.1 | 1449 | 25.8 | 1483 | 27.6 | 1517 | 29.3 |
| 21000 | 3354 | 1222 | 15.3 | 1262 | 17.1 | 1300 | 18.9 | 1337 | 20.6 | 1373 | 22.4 | 1408 | 24.1 | 1445 | 25.9 | 1480 | 27.7 | 1514 | 29.5 | 1547 | 31.3 |
| 22000 | 3514 | 1262 | 16.7 | 1300 | 18.6 | 1337 | 20.4 | 1373 | 22.3 | 1408 | 24.1 | 1442 | 25.9 | 1476 | 27.8 | 1511 | 29.7 | 1545 | 31.5 | 1577 | 33.4 |
| 23000 | 3674 | 1302 | 18.3 | 1339 | 20.1 | 1375 | 22.1 | 1410 | 24.0 | 1444 | 25.9 | 1478 | 27.8 | 1510 | 29.8 | 1543 | 31.7 | 1576 | 33.7 | 1608 | 35.6 |
| 24000 | 3833 | 1342 | 19.9 | 1378 | 21.8 | 1413 | 23.8 | 1448 | 25.8 | 1481 | 27.9 | 1514 | 29.9 | 1546 | 31.9 | 1576 | 33.9 | 1608 | 35.9 | 1640 | 37.9 |
| 25000 | 3993 | 1383 | 21.7 | 1418 | 23.7 | 1452 | 25.7 | 1486 | 27.8 | 1518 | 29.9 | 1550 | 32.0 | 1581 | 34.1 | 1612 | 36.1 | 1641 | 38.3 | 1671 | 40.4 |

*Performance shown is for model AFSW arrangement 1, installation type B - free inlet, ducted outlet. Performance ratings do not include the effects of appurtenances in the airstream. Power rating (BPH) does not include drive losses.*

*required static pressure*

*outlet velocity at given CFM*

*required CFM*

*required fan RPM*

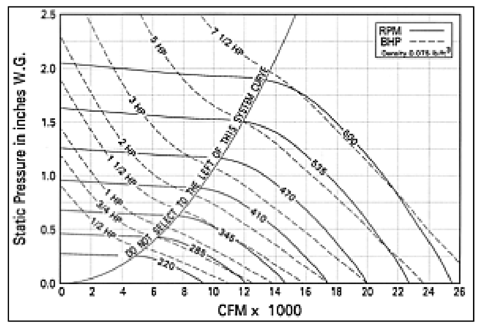
*BHP @ selected performance*

Class I

Class II

Class III

With the use of electronic fan selection programs the trend is to further reduce the amount of printed data and to print only a range of performance for each fan size. There's little doubt that a good electronic selection program such as CAPS can pinpoint a precise selection with minimal effort.




It's also becoming common to see fan performance curves (actually a family of RPM curves) covering the full range of performance printed on the same or adjacent page to the performance table. This format provides a quick snapshot of the total capabilities of one given fan model and size. Locate the desired flow along the x-axis and the specified pressure on the left y-axis. At the point of intersection, you can determine the approximate Fan RPM required. To find the motor size required, move upward to the closest HP line (dotted line). You can quickly review charts for several different fan sizes to determine the most desirable selection.

## Fan Curves

One of the most valuable pieces of information supplied by fan manufacturers is the fan performance curve. Curves are normally supplied for each specific fan on a given project. These curves show the relationship between the quantity of air a fan will deliver and the pressure generated at various air quantities. The curves also show horsepower for a given quantity of flow.

Figure 1 represents the performance for a given fan size and RPM. The flow scale is presented along the x-axis. The pressure scale is presented along the left y-axis. Find the required CFM and move vertically to the SP curve. Read horizontally to the left to read the pressure at that flow.

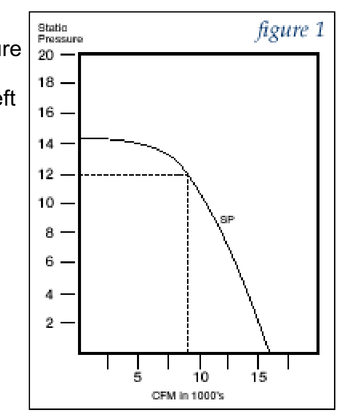



Figure 2 illustrates the effects of speed change. According to the fan laws, CFM varies directly with RPM. The result of reducing the speed is a similar curve in a lower position. Increasing speed results in a similar curve in a higher position.

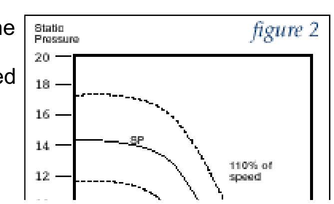


Figure 3 illustrates the addition of the BHP curve. The power scale is presented along the right y-axis. Find the volume on the SP curve and move vertically to the BHP curve. At this intersection, move horizontally to the right-hand scale to read the BHP at that flow.

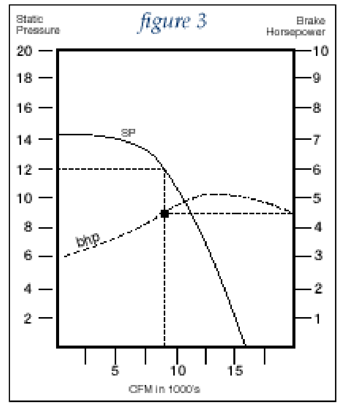


figure 3

The curve shapes in figures 1-3 are typical of centrifugal wheels. Other impeller types have both fan and power curve shapes that vary from those shown. However, the principle of reading the curves is the same.

## System Resistance Curves

System resistance curves are a graphical representation of how a system reacts to a given airflow. The system resistance is the sum of all pressure losses through the duct, all elbows, filters, dampers, coils and any other device that resists flow.

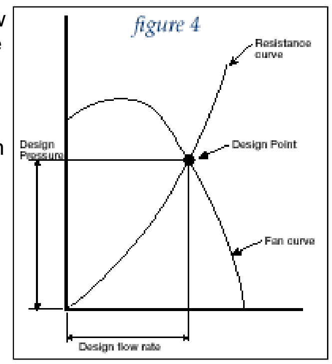


figure 4

Figure 4 shows that the system curve always starts at the origin where flow and pressure are zero. The fan will operate at the point where the system resistance curve intersects the fan curve. For a constant system, with no change in damper settings, etc. the pressure at a given flow varies as the square of the airflow.

The only time the shape of the system resistance curve changes is when the system physically changes. For instance, if a damper is opened, the system resistance is reduced. The result is a lower pressure drop. Closing a damper, or when filters become dirty, increases the systems resistance.

Figure 5 illustrates how the system resistance curve changes with a decrease or an increase in resistance. The new curve shows that as the systems resistance changes, so does the air volume the system pressure at a constant fan RPM.

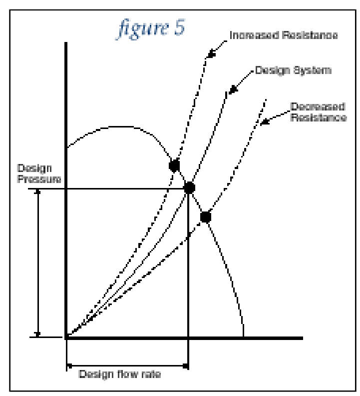
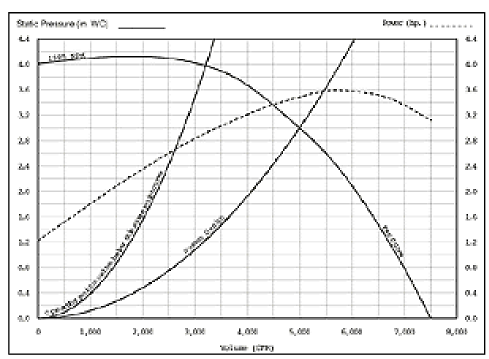


figure 5

Figure 6: is a sample print-out from Greenheck's CAPS program for a specific fan selection. This illustrates the fan curve, the BHP curve, the system design curve, plus a fan surge curve. Fan selection close to, or to the left of the surge curve, is not recommended. Referring to this surge curve aids the designer in selecting fans that are stable and will not go into surge with a minor change to the system.



We have learned that a fan curve is the series of points at which a given fan model and size can operate at a constant RPM. The system

resistance curve is the series of points at which the system can operate. The operating point is where these two curves intersect. Any changes to the fan RPM will cause the point of operation to move along the system curve and changes to the system resistance will cause the point of operation to move up or down the fan curve.

### Fan Laws

Our next step is to understand fan laws. Fan laws, can be used to accurately predict changes (assuming the fan diameter and air density are constant).

### Fan law equations

$$CFM_2 = \frac{RPM_2}{RPM_1} \times CFM_1$$

$$SP_2 = \left(\frac{RPM_2}{RPM_1}\right)^2 \times SP_1$$

$$BHP_2 = \left(\frac{RPM_2}{RPM_1}\right)^3 \times BHP_1$$

Subscript 1: Describes the existing conditions
Subscript 2: Describes the new conditions

The following example is typical of how the fan laws are applied:

A fan installed in a fixed system is operating at:

- CFM = 10,000
- SP = 1.50"
- BHP = 5.00
- RPM = 1,000

What RPM is required to move 25% more air (12,500 CFM) through this system?

NOTE: You can view this example as either the installation now desires more air than planned, or the balancing report showed 25% less air than specified.

### By rearranging the cfm fan law:

$$RPM_2 = \left(\frac{CFM2}{CFM1}\right) \times RPM_1$$

$$RPM_2 = \left(\frac{12{,}500}{10{,}000}\right) \times 1000 = 1250 \text{ RPM}$$

### The corresponding static pressure is:

$$SP_2 = SP_1 \left(\frac{RPM2}{RPM1}\right)^2$$

$$SP_2 = 1.50 \left(\frac{1250}{1000}\right)^2 = 2.34''$$

### The resulting BHP is:

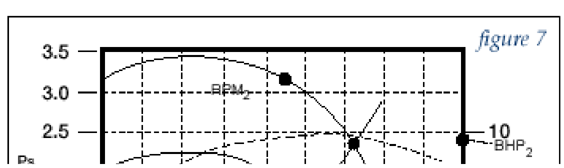
$$BHP_2 = BHP_1 \left(\frac{RPM2}{RPM1}\right)^3$$

$$BHP_2 = 5.00 \left(\frac{1250}{1000}\right)^3 = 9.77 \text{ BHP}$$

According to the fan laws, in order to use the original fan, the speed must be increased from 1000 RPM to 1250 RPM, the motor must be changed from a 5 HP to 10 HP.

Figure 7 illustrates fan curves for both the original and new fan performance.

Important: Check to make sure that the new RPM does not exceed the



maximum allowable RPM for the
existing fan. Maximum RPMs are shown in fan catalogs. You should consult the fan manufacturer for additional information or if you would like to review the application.

More detailed information on these subjects can be found in both AMCA and ASHRAE publications.



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